

UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR TEST

Upflow Anaerobic Sludge Blanket Reactor Test Unit

The upflow anaerobic sludge blanket process consists of treating wastewater in a closed vessel containing anaerobic sludge. Treatment occurs as the influent passes upwards through the sludge blanket (bed) into a settling zone that contains a baffle and a gas/solids separator cone. The baffle directs the wastewater up into the cone. Gas and solids are separated from the wastewater as it passes down and around the separator. The treated wastewater is then withdrawn from the upper portion of the vessel. The gas generated from the decomposing matter is collected at the top of the cone and extracted. Depending on the type of wastewater being treated, UASBR may be equipped to mix the sludge bed and to recirculate the wastewater through the reactor.

The UASBR at the Adams facility consisted of a 3,000-gallon, polyethylene, closed-top, cone tank. The UASBR was initially fitted with a baffle, hypalon gas/solids separator cone and sampling ports. Throughout testing, modifications were made to the UASBR. These included the addition of sludge mixing and recirculation systems along with other modifications to influent and effluent piping, carbon injection system, and other ancillary appurtenances. The separator cone was replaced twice. Initially the hypalon cone was replaced with a Lexan cylinder. Eventually, the cylinder was replaced with a cone made from high-density polyethylene plastic. Figure 4 shows the final layout of the UASBR system.

UASBR Operations

Operation of the UASBR is divided into three periods. During Period 1, September 1992 through April 1993, the UASBR was operated using a granular sludge obtained from an anaerobic process that treated bakery waste. Operation was stopped due to failure of the hypalon gas/solids separator cone. Period 2, July 1993 through August 1993, involved operation, again using the remaining granular bakery sludge, after the hypalon separator cone was repaired and other modifications were made. Testing was stopped due to the breakup and loss (carryover) of the granular sludge from the reactor. During Period 3, September 1993 through November 1995, testing was conducted using a wastewater treatment plant sludge obtained from a mixed anaerobic digester.

The UASBR was operated continuously, 24 hours a day, seven days a week for all the test periods. Initially, field data on flow rates, dissolved oxygen, nitrate, and temperature were collected daily. In June 1994, data collection was reduced to six days a week when weekend staffing was reduced. Electrical conductivity measurements were obtained weekly. The parameters of pH, sludge volume, and alkalinity were later added to the weekly field measurements at various times during the test program. Samples of the influent and effluent streams were collected weekly and sent to the university's laboratory for analyses of total selenium, selenite, total suspended solids, volatile to solids, total dissolved solids, and total organic carbon. Analyses for sludge were performed periodically to document its makeup over time. The volume of gas produced in the UASBR was recorded during Period 3. Gas samples were collected at various times during the later portion of Period 3 to determine constituent makeup of the gas and to perform mass balances.

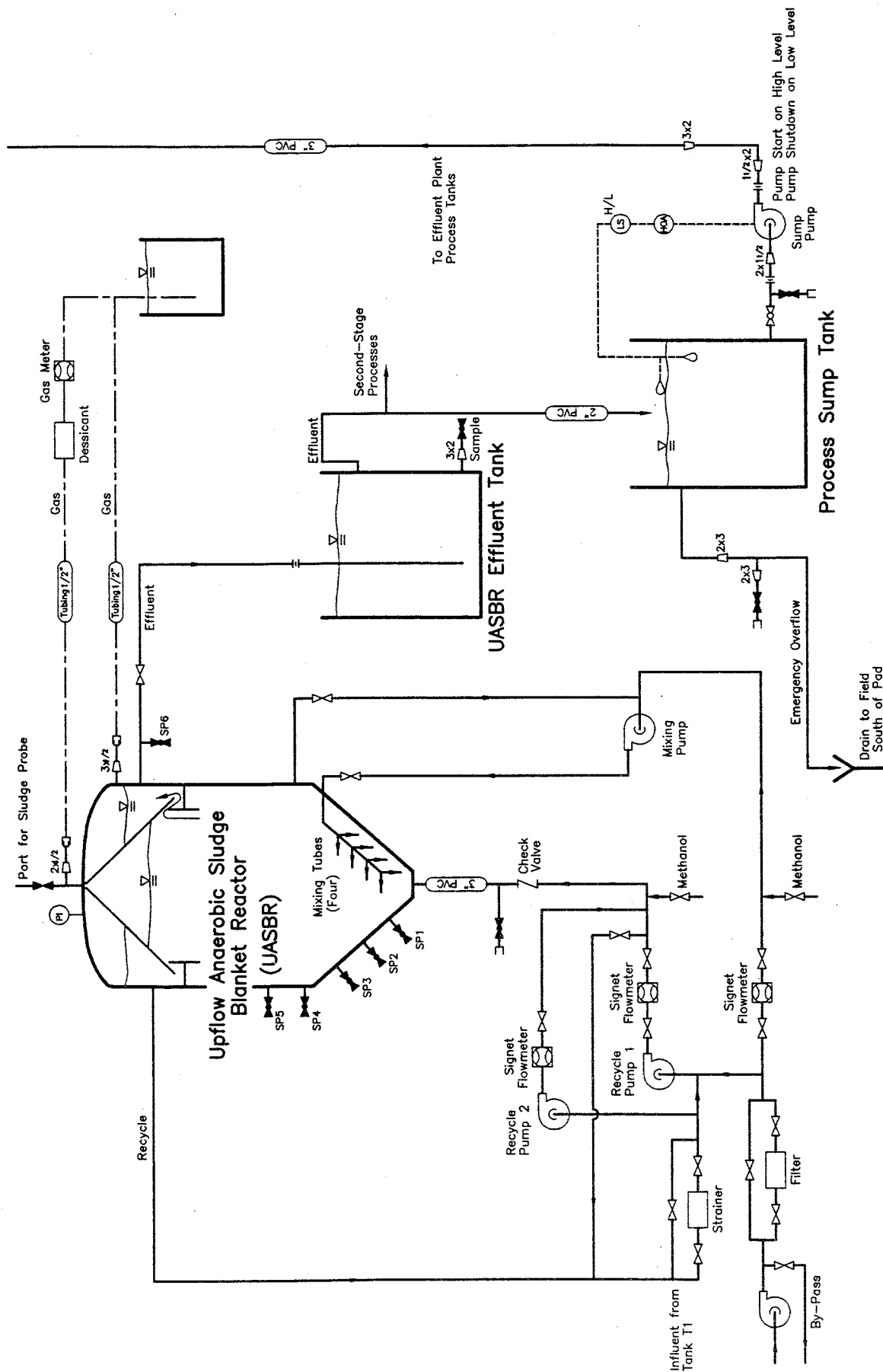


Figure 4. Upflow Anaerobic Sludge Blanket Reactor Schematic

Period 1 Operations - September 14, 1992 through April 29, 1993

A 6,000-gallon shipment of granular sludge arrived at the Adams facility from Kansas City, Missouri, on September 14 and the arrival marked the beginning of Period 1. This date is also defined as Day 0 for all testing at the Adams facility. Period 1 operations lasted through April 29, 1993 (Day 227). Granular sludge was obtained from a dormant UASBR that treated a high COD bakery waste. This saved months in start-up time that would have been needed to generate a new supply of sludge. Half of the sludge was put into the UASBR while the remainder was placed in two fiberglass tanks for use at a later date. The settled granules filled the bottom cone of the reactor tank and measured approximately 500 gallons.

The first 14 days of operation in Period 1 were spent acclimatizing the sludge to drainage water and modifying the effluent and recycle piping to prevent air-entrainment in those streams. Flow of drainage water through UASBR was gradually increased from 0.5gpm to 2gpm by October 19 and remained at this flow for the remainder of Period 1. The process was operated at an average upflow rate (influent flowrate added to the recycle flowrate) of 84 gpm, or at an average upflow velocity of 1.82 gallons per minute per square foot (gpm/ft^2) in the reactor throughout the period. The carbon required for denitrification to the influent stream averaged 355 mg of methanol per liter of drainage water (mg/L) throughout Period 1. The carbon dosage exceeded the amount required for denitrification (USEPA) to ensure the UASB process was not limited by carbon. Previous work by Binnie and others has shown that selenium reduction occurs after the nitrate has been reduced.

Modifications were made to the UASBR system throughout Period 1. On February 21, 1993, (Day 160), provisions were made for additional mixing of the sludge bed by diverting 20 gpm of the recycle flow and injecting the stream at various depths into the sludge bed with a PVC pipe inserted through the top of the reactor. This setup provided horizontal mixing of the sludge. Modifications were made to the influent and effluent piping at various dates to improve the control of flow through the reactor. Also, the methanol injection system was modified to improve system reliability. For Period 1, methanol dosages ranged between 177 and 660 mg/L with standard deviation of 70 mg/L. Control of the methanol feed system to maintain a constant dosage was a continuing problem until late in the testing program.

A series of events which were first documented on January 13, 1993, (Day 121), led to the eventual shut-down of the UASBR on April 29, 1993, (Day 227). Period 1 testing ceased because of the failure of the gas/solids separation cone and slippage of the baffle to the bottom of the UASBR.

Period 1 Results

The total and soluble selenium and selenite concentrations for the agricultural drainage water for Period 1 are shown by Figure 5. Total selenium (Tse) ranged between 433 ug/L and 592 ug/L and averaged 511 ug/L while soluble selenium (Sse) ranged between 360 ug/L and 564 ug/L and averaged 482 ug/L. Selenite concentrations for the period averaged 2 ug/L. These selenium values for the raw drainage water were typical for the entire testing program.

Figure 6 shows the UASBR effluent selenium values for the period. The effluent Sse concentration gradually increased until it leveled to above 300 ug/L on December 28, 1992. It remained at that level until January 15, 1993, when reduction improved and lowered to under 200 ug/L. As previously stated in the operations section, modifications to mix the sludge bed were made on February 15. From February 15, the effluent Sse concentration gradually improved and reached 57 ug/L on March 8. After March 8, the effluent Sse concentration increased, was erratic and appeared to be indicative of problems with the gas/solids separation cone in the reactor.

The percentage of soluble selenium reduced in the UASBR for Period 1 is shown in Figure 7. Sse removal was in excess of 80% until November 23. Between November 23 and February 26, 1993, Sse removal fluctuated from a high of 75% to a low of 32%. Again, removal rose above 80% from March 1 through March 8 before the apparent failure of the hypalon gas/solids cone. The field measurements for influent and effluent nitrate concentrations are shown in Figure 8. All values for nitrate concentration for the project and in this report are stated in mg/L as N. The influent concentration ranged between 19 mg/L and 50 mg/L and averaged 40 mg/L. The effluent residual was between 0 mg/L and 4 mg/L and averaged 2.2 mg/L until March 18 after which the effluent residual substantially increased. Again the effluent values indicated problems with the hypalon gas/solids cone. Laboratory measurements consistently corresponded to the field values.

Influent and Port 5 dissolved oxygen and Port 5 temperature values are shown in Figure 9. Port 5 corresponded to the 1,100-gallon level of the reactor and was 1.5 feet above the top of the reactor's conical bottom cone. The level of sludge was usually below Port 5 for the duration of the test program. The influent DO concentration ranged from a low of 5.5 mg/L to a high of 11 mg/L and averaged to 9.3 mg/L. The effluent concentration averaged 0.3 mg/L for the period. The reactor's temperature is shown to compare temperature to that of the other monitored data.

Influent and effluent total and volatile suspended solids concentrations are shown in Figure 10. The feed TSS and VSS concentrations averaged 26 mg/L and 15 mg/L, respectively. Until March 1, 1993, the effluent TSS and VSS values averaged 56 mg/L and 26 mg/L, respectively. After March 1, both effluent values increased and was thought to be attributed to the failure of the hypalon gas/solids cone.

The influent and effluent total organic carbon concentrations are shown in Figure 11, while methanol dosage is shown in Figure 12. The feed TOC concentration remained relatively stable through this test period and averaged 9 mg/L. The effluent TOC concentration averaged 21 mg/L and was always equal to or in excess of the influent concentration except on December 21, 1992, when the influent and effluent concentrations were 11 mg/L and 12 mg/L, respectively. A discussion of methanol dosage and the dosing system is provided in the previous operation section.

Period 2 Operations - July 19, 1993 through August 19, 1993

Testing resumed after the separation cone was repaired, the baffle was bolted to the side of the reactor, and other modifications were made. The gas extraction piping was modified and the

Figure 5
UASBR Period 1 - Influent Total Selenium,
Soluble Selenium and Selenite

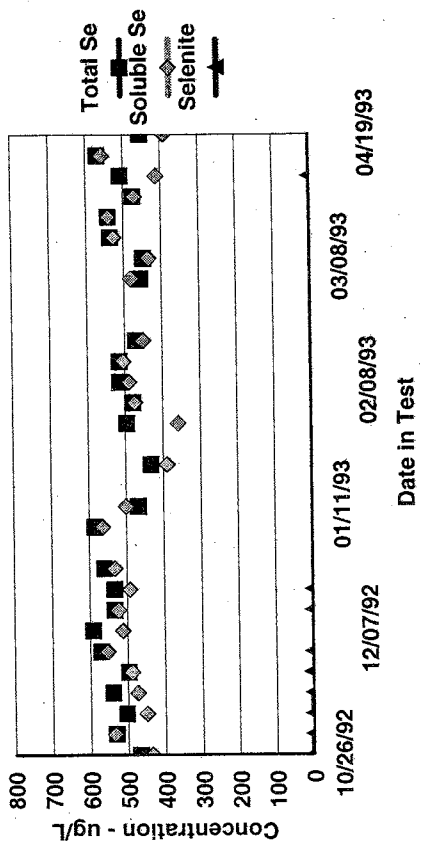


Figure 6
UASBR Period 1 - Effluent Total Selenium,
Soluble Selenium and Selenite

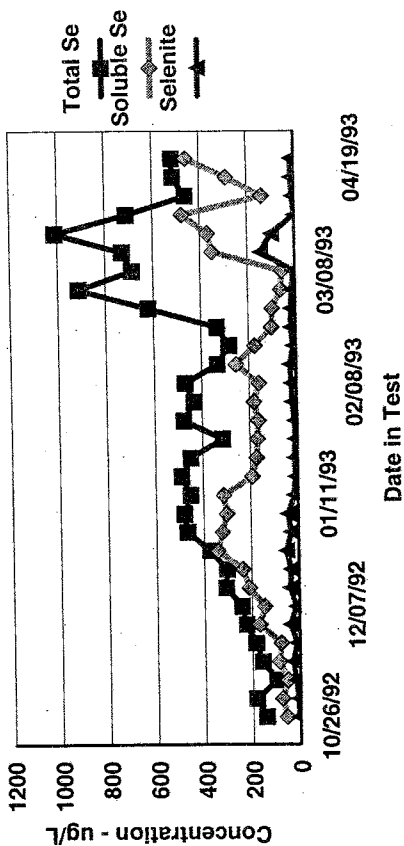


Figure 7
UASBR Period 1 - Percentage of
Soluble Selenium Reduced

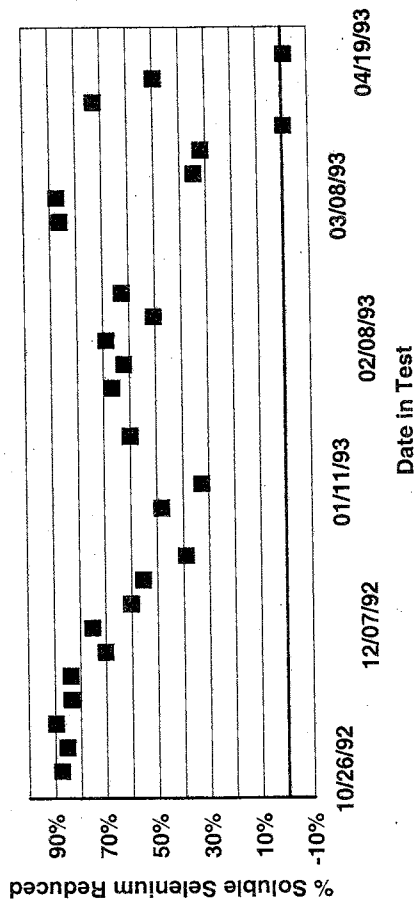


Figure 8
UASBR Period 1 - Influent and Effluent
Nitrate

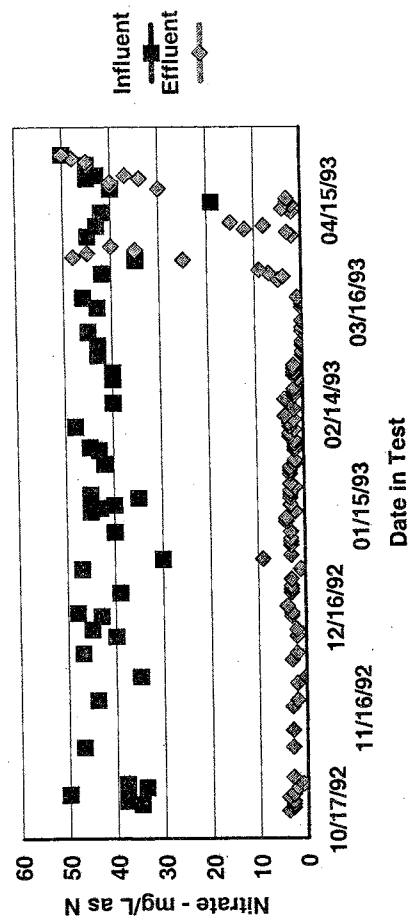


Figure 9
UASBR Period 1 - Influent and Port 5
Dissolved Oxygen and Port 5 Temperature

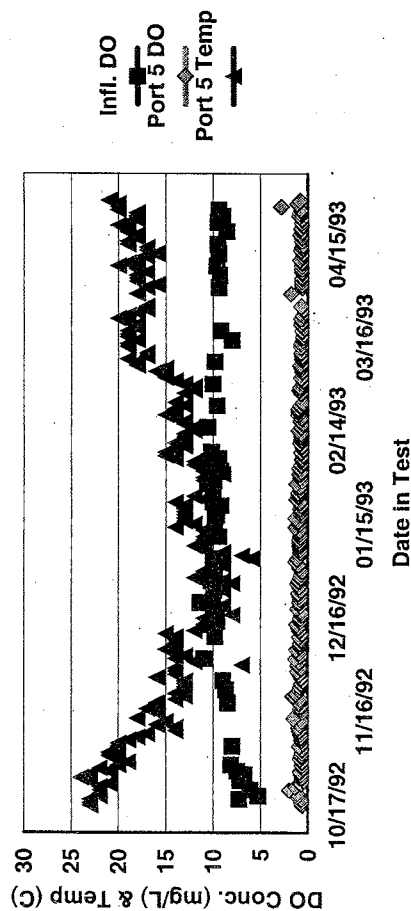


Figure 10
UASBR Period 1 - Influent and Effluent
Total & Volatile Suspended Solids

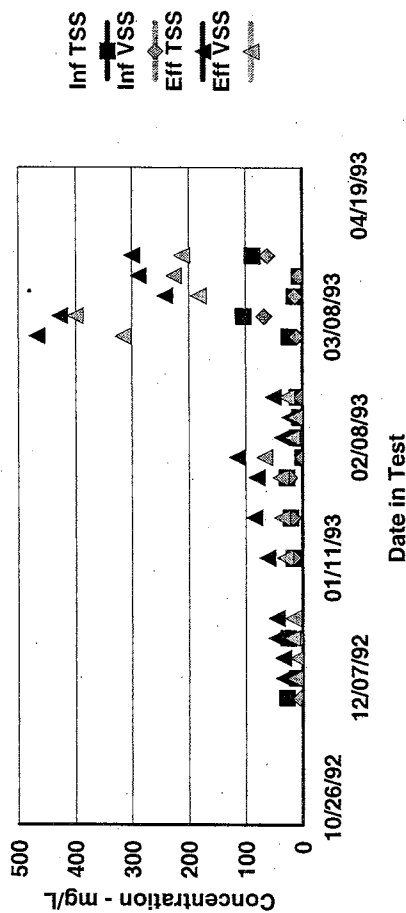


Figure 11
UASBR Period 1 - Influent and Effluent
Total Organic Carbon

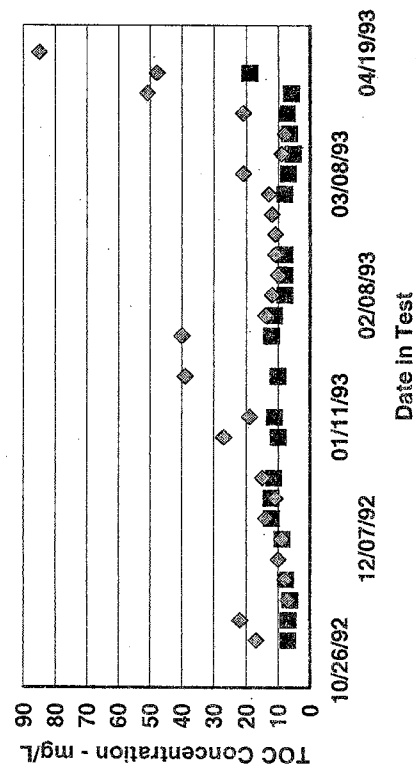
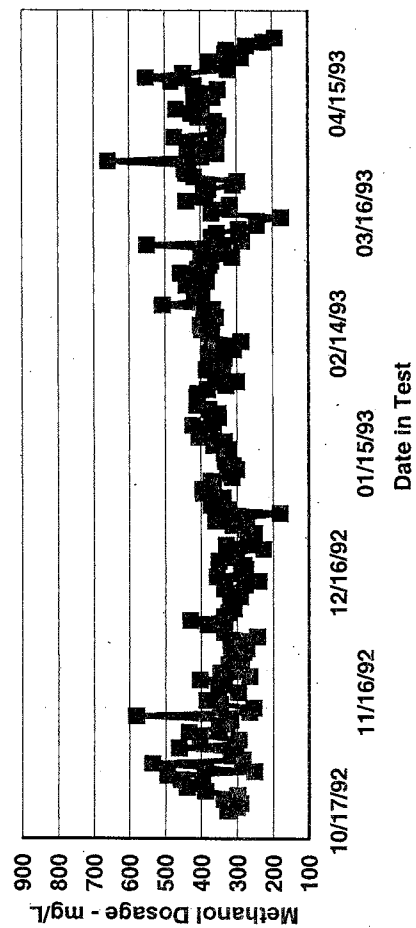


Figure 12
UASBR Period 1
Methanol Dosage



effluent and recycle piping were separated to operate independently of each other. Another recycling or sludge mixing system was added to the reactor. Lastly, an apparatus to optically probe the reactor to determine the interface of the sludge bed and settling zone was assembled, and ports to probe the opacity of the reactor's contents were installed on the reactor. The UASBR was restarted on July 19, 1993 (Day 308), with about 920 gallons of the granular, bakery sludge.

Period 2 testing was short-lived and ended on August 19, 1993 (Day 339). Sludge in the effluent and scum floating on top of the liquid in the reactor were observed throughout the period. The scum contained clumps of agglomerated sludge granules and gas.

Flow through the system for the first three weeks averaged 1.8 gpm, with an average recycle rate of 81 gpm, which corresponds to an effective average upflow velocity of 1.80 gpm/ft^2 . On August 19 (Day 339), the sludge mixing system was put into operation at 76 gpm. Together with the recycle and throughput flows, this provided an effective upflow velocity of 3.42 gpm/ft^2 . Methanol dosage averaged 375 mg/L, with a range between 61 and 646 mg/L and a standard deviation of 124 mg/L. The reactor was usually probed twice a week. Probes were performed daily for the last days of operations when readings measured approximately 100 gallons of sludge in the reactor. After shutdown, the remaining sludge was removed from the reactor and stored on site in 55-gallon plastic drums.

Period 2 Results

Period 2 operations lasted a month, from July 19 to August 19, 1993. This time frame was inadequate to achieve stable operations. Only a brief discussion of operation results is presented.

The average effluent S_{se} and nitrate concentrations for Period 2 were 180 ug/L and 7 mg/L as N, respectively. The percentage of S_{se} removed during the period ranged from a low of 6% to a high of 89%. The problem of keeping sludge in the reactor is evidenced by the effluent total and volatile suspended solids concentrations, which averaged 345 mg/L and 236 mg/L, respectively.

Period 3 Operations - September 1, 1993 through November 21, 1995

The UASBR was restarted on September 1, 1993 (Day 352), using anaerobic sludge obtained from the mixed-sludge digesters at Fresno's wastewater treatment plant. Unlike the granules of the bakery sludge previously tested, the digester sludge was composed of fine solids typically found in wastewater digesters. Only a minimal amount of sludge, about 200 gallons, could be maintained in the reactor despite periodic addition of sludge to the reactor throughout October and November. Upflow velocities through the reactor for October and November ranged between 0.05 and 0.87 gpm/ft^2 . To provide a time reference when treatment trains were established, the two fluidized bed reactors and the two slow sand filters were put on-line in the second week of October 1993.

On December 20 (Day 462), approximately 1,700 gallons of activated sludge and 0.5 cubic feet of sand (to support biological growth) were added to the black, viscous digester sludge that remained in the reactor. The activated sludge was obtained from Selma-Fowler-Kingsburg wastewater treatment plant, which also supplied the sludge used in the investigations at Murrieta

Farm by Binnie. For the next eight days, while hair and other debris in the activated sludge were being flushed through the reactor, the influent flow rate into the reactor was incrementally increased from 2.5 to 5 gpm, and the upflow rate through the reactor was targeted at 40 gpm (upflow velocity 0.87 gpm/ft^2). On December 30, the target upflow rate was increased to 50 gpm (upflow velocity 1.08 gpm/ft^2) for a few days and then gradually decreased to 40 gpm on January 7, 1994. By December 31, the sludge volume had decreased to about 210 gallons. From January 7, the reactor operated at an influent rate of 5 gpm with an upflow rate of 40 gpm (upflow velocity of 0.87 gpm/ft^2) until January 31 when the testing was shut down for a day due to maintenance activities conducted by the electrical power purveyor. Sludge volume measured around 320 gallons.

The UASBR was restarted on February 2, 1994 (Day 506) at an influent flowrate approximately 5 gpm, with an upflow rate of 10 gpm (upflow velocity of 0.22 gpm/ft^2) and average carbon dosage of 453 mg/L. The reactor was turned off on April 26 (Day 589), due to loss of sludge from the reactor. Operations were restarted on May 4 at identical parameters previous to shut down on April 26. On June 15, the feed flow rate was incrementally increased and the recycle flow rate was decreased in identical increments until the entire upflow rate was that of the feed flow rate without a recycle flow. This change was accomplished on July 14 (Day 668). The UASBR was shut down from June 23 (Day 616) to June 25 to replace the failed hypalon gas/solids separator cone with a Lexan cylinder. The grommets holding the bottom of the hypalon cone in position ripped through the hypalon fabric.

For a short duration, from July 3, 1994 to August 1, 1994, the UASBR was operated to maintain a nitrate residual in the effluent. The target carbon dosage was lowered to 230 mg/L. This was done to provide nitrate reductase for the downstream reactors, fluidized bed reactor 1 and both slow sand filters, for they were not providing any additional selenium reduction. In other research, Macy (UCD 1992) found that the reduction of selenite to elemental selenium required nitrate reductase, the enzyme responsible for nitrate reduction. The slow sand filters were exhibiting nitrifying characteristics since March 1993.

From August 2, 1994 through November 1995, targeted carbon dosage for the UASBR varied and ranged between 300 mg/L and 400 mg/L. Table 3 shows dates, targeted dosages, actual average dosages, and standard deviation of actual dosages for the entire Period 3.

Table 3
UASBR Period 3 Methanol Dosages*

Date		Target	Actual	Standard
From	To	Dosage	Average	Deviation
08/31/93	05/30/93	500	406	132
05/31/94	06/08/94	600	578	143
06/08/94	06/14/94	475	500	99
06/15/94	06/16/94	400	476	10
06/17/94	06/28/94	325	525	96
06/29/94	07/04/94	285	289	11
07/05/94	07/12/94	250	256	31
07/13/94	08/01/94	250	236	72
08/02/94	08/19/94	300	307	24
08/20/94	10/10/94	400	382	33
10/11/94	04/02/94	350	354	46
04/03/95	05/01/95	325	335	18
05/02/95	11/21/95	400	385	24

*Dosage units are mg/L as methanol

The UASBR was operated with a feed flow rate of 10 gpm (upflow velocity of 0.22 gpm/ft²) without a recycle flow from July 14 through February 13, 1995 (Day 882), when all plant operations were shut down due to flooding of the discharge field. During this period, on August 1, 1994 (Day 686), the phosphate feed to the incoming drainage water was reduced to 0.25 mg/L as P from 0.5 mg/L. On February 1, 1995 (Day 870), a dye test was performed on the UASBR to investigate channeling and short-circuiting.

The UASBR was restarted on February 18 (Day 887), at a feed flow rate of 10 gpm without recycle (upflow velocity 0.22 gpm/ft²). The feed flow rate was decreased to 5 gpm with a 5 gpm recycle flow rate producing an upflow velocity of 0.22 gpm/ft² on February 23. The UASBR was operated at these parameters until March 10 (Day 907), when all operations at the Adams facility were suspended due to flooding at the site from storms that devastated the western side of the San Joaquin Valley and washed out a bridge on Interstate 5 that crossed Arroyo Pasajero.

Testing with UASBR resumed on March 27 (Day 924), with a feed flow rate of 2 gpm without recycle. A few days later, the feed flow rate was increased to 5 gpm and recycle was added at a flow rate of 5 gpm. It remained at those parameters until July 7 (Day 1026), when the reactor was shut down to install a pre-manufactured high-density polyethylene gas/solids separation cone fabricated by Precision Plastics of Fresno, California to meet the demand of the reactor. The cone was made to collect and to adequately measure the gas produced so that a mass balance for selenium could be conducted for the UASBR. Data for mass balance calculations were collected during September, October, and November 1995.

The installation of the cone was completed in three days. The level of water in the reactor was lowered below the Lexan cylinder and baffle, two pre-formed angle support rings were bolted

around and to the side of the tank at the top of the reactor, the tank was cut between the support rings, and the top of the tank was removed to install the cone. This was the first time the interior of the reactor could be fully observed. Previous observations and work performed inside the UASBR had to be accomplished through a 24-inch-diameter port. Balls of agglomerated biomass ranging from 1 to 2 inches in diameter, which covered the surface of the remaining water in the reactor, were removed before the HDPE cone was installed.

The reactor was restarted on July 10 (Day 1029) at a feed flow rate of 5 gpm and a 10 gpm upflow rate (upflow velocity of 0.22 gpm/ft^2) until July 14, when the UASBR operations were suspended to repair the cone. A kink in the gas line to the gas meter caused a buildup of gas pressure under the cone, which resulted in slippage of a few of the cone's holddown angles from the reactor tank's retention angles. The cone tilted and buckled. Repairs were completed on July 20 (Day 1039), and the operations resumed at previous parameters.

The influent flow rate was maintained at 5 gpm (0.10 gpm/ft^2) until August 23 (Day 1073) when it was increased to 18 gpm (0.39 gpm/ft^2) without a recycle flow. The Lincoln pump station pump discharge line ruptured, and the UASBR was shut down from August 29 through September 1 for repair. The phosphate dosage for the raw drainage water was increased to 1.3 mg/l as P from 0.25 mg/L when the UASBR was restarted on September 2 (Day 1083), at a feed flowrate of 5 gpm and an upflow rate of 20 gpm (upflow velocity of 0.43 gpm/ft^2). Operation remained at those parameters until all testing at the Adams facility was stopped on November 21, 1995 (Day 1164).

Period 3 Results

The selenium values for agricultural drainage water were fairly consistent with those of Period 1. Period 3 selenium values for the influent drainage water are shown in Figure 13. Tse ranged between 411 ug/L and 706 ug/L and averaged 523 ug/L, while Sse ranged between 393 ug/L and 736 ug/L and averaged 506 ug/L. Selenite concentrations for the period averaged 3 ug/L. The UASBR effluent selenium concentrations for Period 3 are shown in Figure 14, while the percentage of Sse reduced is shown in Figure 15. The best Sse removal in Period 3 occurred during a three week period from May 9 through June 1, 1994, and hovered around 80%. This removal was accomplished when the reactor was fitted with the hypalon g/s cone. The hypalon cone failed later that month and on June 23 (Day 616) was replaced with a Lexan cylinder. The only other occurrence when Sse removal breached the 80% removal level was on August 3, 1994. On August 10, Sse removal dropped to 34%. After August 10 through to the end of testing on November 21, 1995, the Sse removal values fluctuated weekly, but the slope of the trend line was positive. During this 16-month period, Sse removal rose above 60% on six occasions. Installation dates for Lexan cylinder and HDPE cone are shown by upper triangles in Figure 14.

Figure 16 shows the influent and effluent nitrate field measurements. Again, all nitrate concentration values for the project and in this report are in terms of mg/L as N. Influent nitrate concentration varied from a low of 9 mg/L to a high of 47 mg/L and averaged 29 mg/L, which resulted in a standard deviation of 6 mg/L. The effluent nitrate concentration averaged 9 mg/L with a standard deviation of 7 mg/L.

Figure 13
UASBR Period 3 - Influent Total Selenium,
Soluble Selenium and Selenite

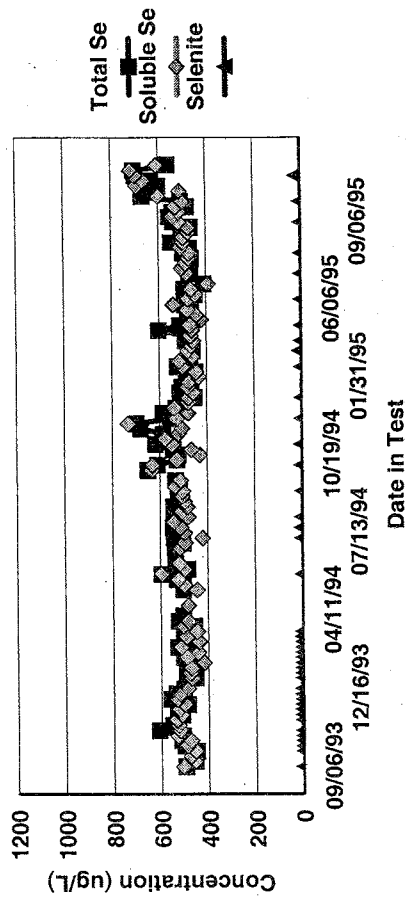


Figure 14
UASBR Period 3 - Effluent Total Selenium,
Soluble Selenium and Selenite

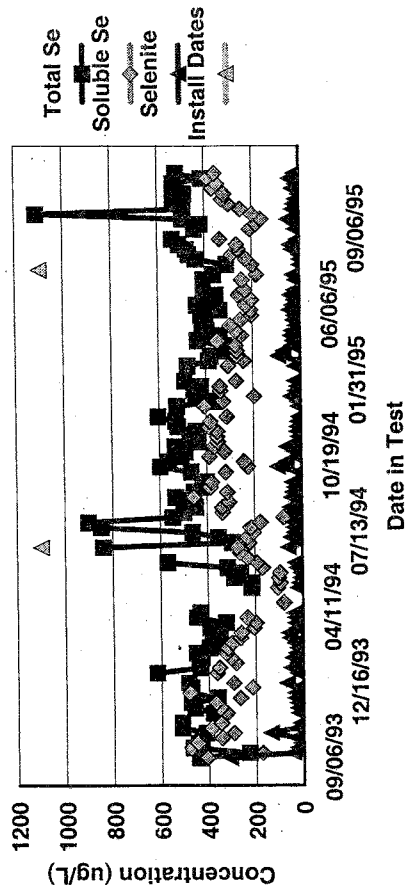


Figure 15
UASBR Period 3 - Percentage of
Soluble Selenium Reduced

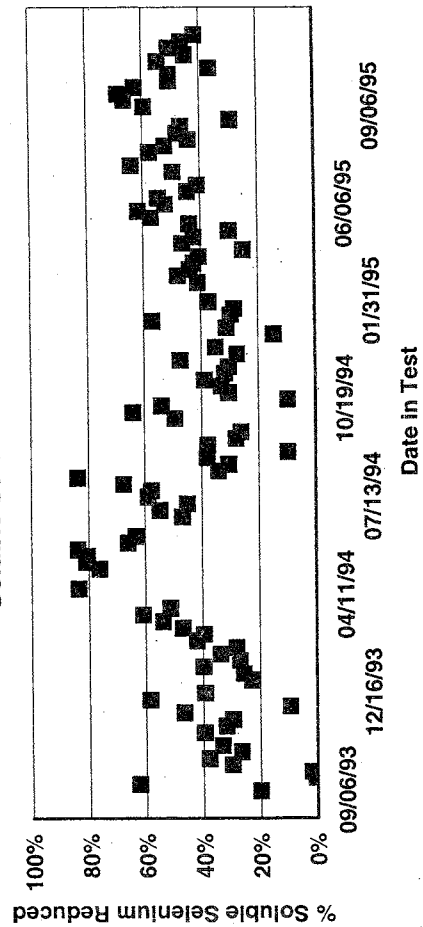
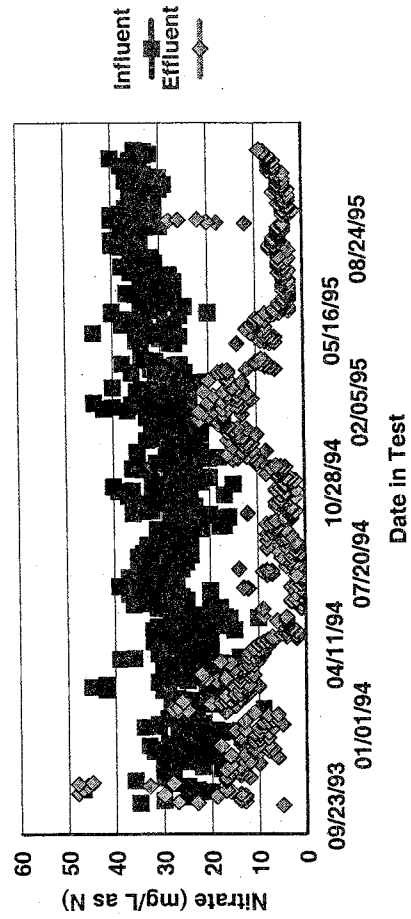


Figure 16
UASBR Period 3 - Influent and Effluent
Nitrate



Influent and Port 5 dissolved oxygen and Port 5 temperature values are shown in Figure 17, while Figure 18 compares Port 5 to ambient temperatures. The influent DO concentration averaged 8.8 mg/L, while Port 5's DO concentration averaged 0.8 mg/L. The reactor's temperature did not experience the extreme highs and lows of the ambient temperature, but was parallel with a time offset.

The influent and effluent total organic carbon concentrations are shown in Figure 19, while methanol dosage is shown in Figure 20. The feed TOC concentration averaged 9 mg/L with a standard deviation 6 mg/L. The effluent TOC concentration was continuously in excess of the feed TOC and averaged 61 mg/L with a standard deviation of 24 mg/L. Figure 20 shows the results of the modifications made to the carbon dosing system. Dosing became more stable as operations progressed.

Figure 21 shows the influent and effluent alkalinity concentrations for Period 3. Alkalinity analyses were performed on a weekly basis and began at the end of December 1994 and continued until the end of the project in November 1995. Influent and effluent alkalinity concentrations averaged 191 mg/L as CaCO_3 and 391 mg/L as CaCO_3 , respectively.

The UASBR volumes of sludge plotted in Figure 22 are calculated values. Measurements were taken with a photoelectric probe, which detected the depth of the sludge bed. From the geometry of the reactor, the volume was determined from the measured depth. Since the volume was measured by a photoelectric cell, a correlation between sludge volume and sludge density could not be determined. The average sludge volume for Period 3 operations was 550 gallons.

Figure 23 shows the total dissolved solids concentrations of the influent and effluent. Throughout the entire period, there was a reduction of TDS concentration from the influent to the effluent. The influent and effluent TDS concentrations averaged 8,228 mg/L and 8,002 mg/L, respectively.

Influent and effluent volatile suspended solids concentrations are shown in Figure 24. The influent and effluent VSS concentrations averaged 5 mg/L and 20 mg/L, respectively. Although not shown, the influent and effluent total suspended solids concentrations increased through the process and averaged 18 mg/L and 37 mg/L, respectively.

Figure 17
UASBR Period 3 - Influent and Port 5
Dissolved Oxygen and Port 5 Temperature

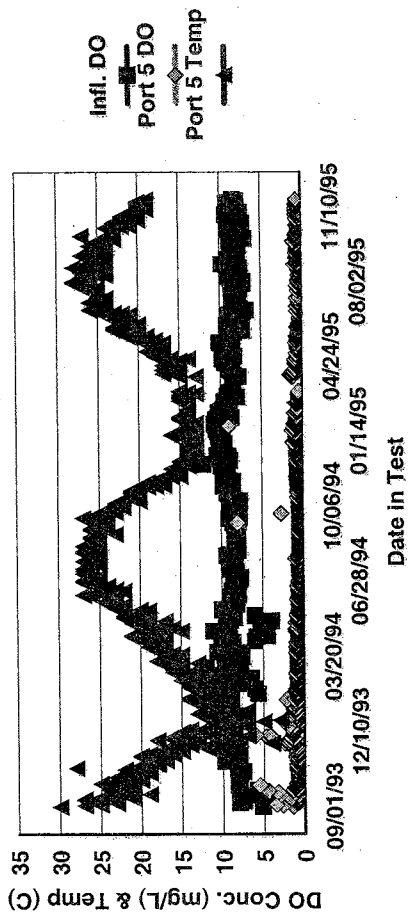


Figure 18
UASBR Period 3
Port 5 and Ambient Temperature

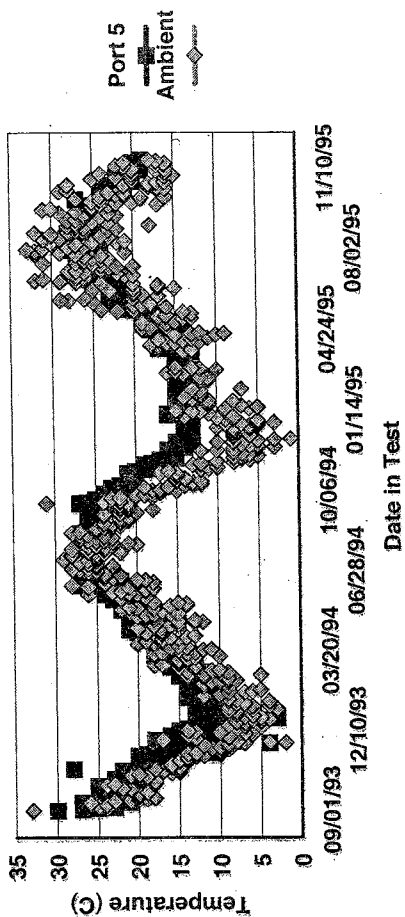


Figure 19
UASBR Period 3 - Influent and Effluent
Total Organic Carbon

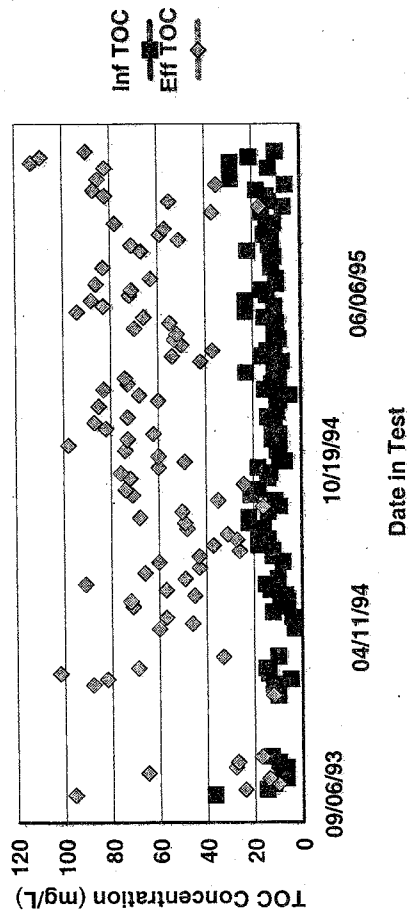


Figure 20
UASBR Period 3
Methanol Dosage

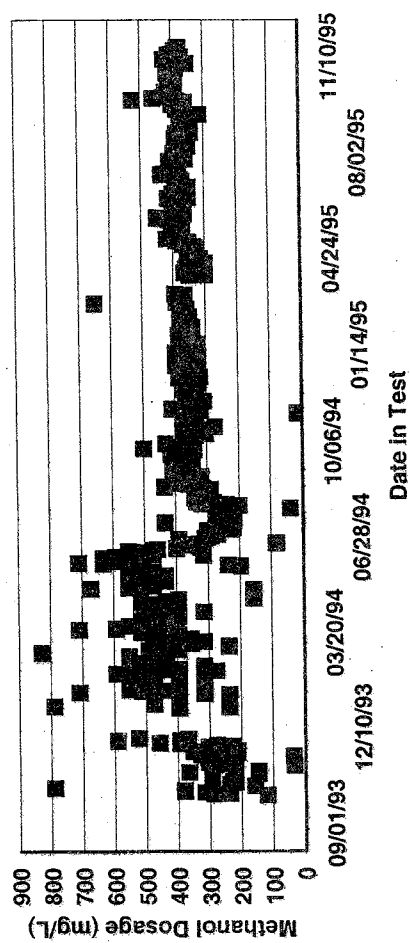


Figure 21
UASBR Period 3
Influent and Effluent Alkalinity

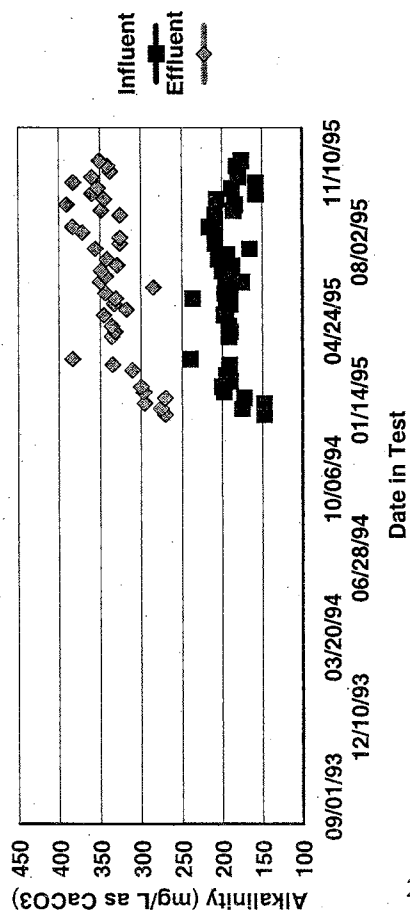


Figure 22
UASBR Period 3
Sludge Volume

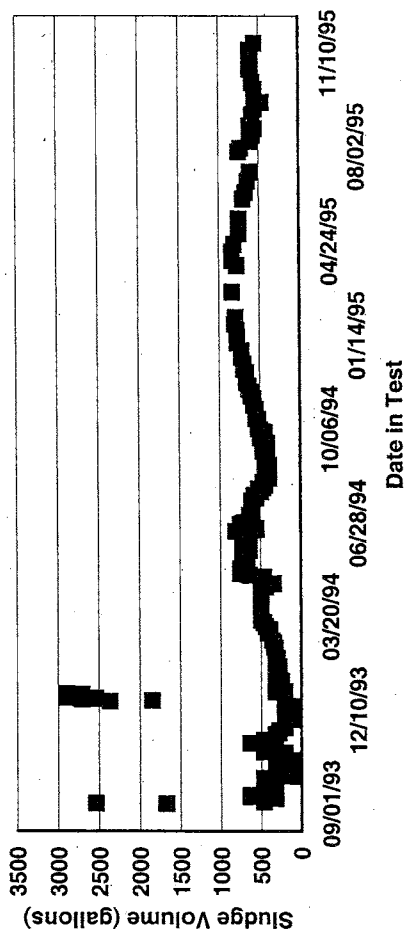


Figure 23
UASBR Period 3 - Influent and Effluent
Total Dissolved Solids

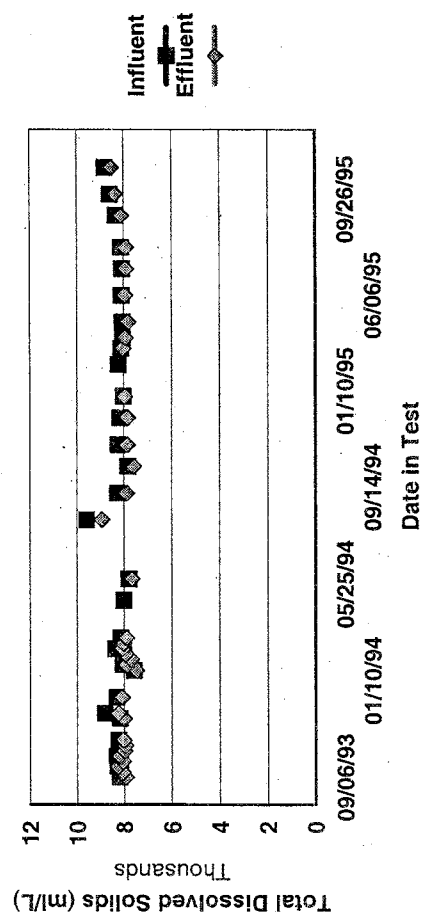


Figure 24
UASBR Period 3 - Influent and Effluent
Volatile Suspended Solids

